Effects of Reactive Ion Etching on Conductivity of NbAs

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Primary CNF Tools Used: Veeco Icon AFM, PT 720-740 RIE, Zeiss Supra SEM, Zeiss Ultra SEM

Abstract:

The continuation of Moore's Law has resulted in persistent downscaling of transistors and current copper (Cu) interconnects resulting in performance bottlenecks when interconnect dimensions are below the electron mean free path (~40 nm) of Cu [1]. Since Cu exhibits high resistance at such dimensionsscales, resistance-capacitance (RC) signal delay and high-power consumption result in lower overall performance [1]. Topological semimetals possess topologically protected conducting surface states that result in low resistivity at low dimensions [2]. Thus, they are of interest in the discovery of novel materials to replace Cu interconnects.

One such material is the Weyl semimetal niobium arsenide (NbAs). We have shown single crystal NbAs nanowires, produced by nanomolding, which has previously been shown to possess conductivity comparable to that of Cu at desirable length scales [3]. However, the promising resistivity trends of NbAs must be studied further as a function of size at sizes between these 10 nm and bulk crystals. has not been extensively studied aIn addition, nd the effects of surface damage on conductivity due to various processing techniques has not been reported must be explored.

In this work, we use reactive ion etching (RIE) to reduce the size of focused ion beam (FIB) produced NbAs nanoscale samples prepared by focused ion beam (FIB) milling and examine the trends in resistivity as a function of NbAs size and RIE conditions. We show that NbAs can be etched roughly linearlycontrollably and reliably under mild RIE conditions and resistivity continuously decreases as NbAs is reduced in size. This allows for greater understanding of resistivity scaling and its mechanisms in NbAs.

Summary of Research:

We etched fabricated single crystal NbAs nanoslabs using FIB milling and created electrical devices. A completed device is shown in Figure 1. Length and width measurements were extracted from scanning electron microscopy (SEM) images. Atomic force microscopy (AFM) was used to measure the height of the slabs. The cross-sectional area of the slabs was calculated from this data. Resistance measurements were acquired via 4-point probe current and voltage measurements. The measured resistance was converted to resistivity When combined with dimensional data, we were able to calculate the resistivity of our NbAs slabsfor the NbAs slabs.

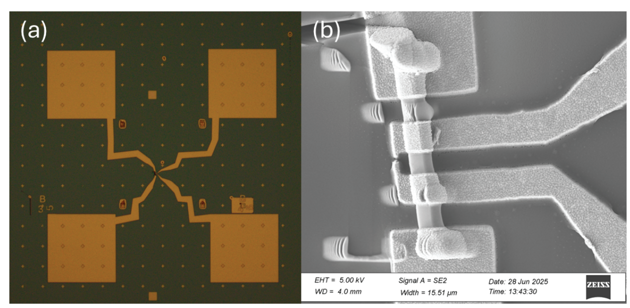

Figure 1: (a) Optical image of NbAs Device 3. (b) SEM image of Device 3.

The slabs were successively etched with RIE at 10 mTorr with 60 W of power using 30 sccm Cl_2 and 10 sccm CF_4 at varying etching times. Afterwards, AFM and resistance measurements were repeated to observe the changes in height and resistivity of the slabs. Figure 2 shows how uncertainty in the height measurements and thus etching calibration occurs due to the shape of the AFM tip as well as the geometry of the sample placed on the substrate. Additionally, we take into accountconsider the etching of the substrate when calculating the effects of etching. Overall, we are able to etched our devices at approximately 5-7 nm per minute.

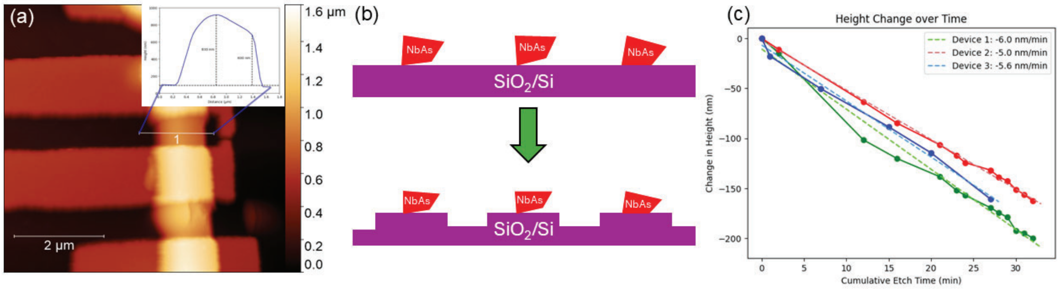

Figure 2: (a) AFM image with height profile of Device 3 pre-etching. (b) Schematic showing etching of substrate layer during RIE. (c) Plot of NbAs height change with respect to etching time.

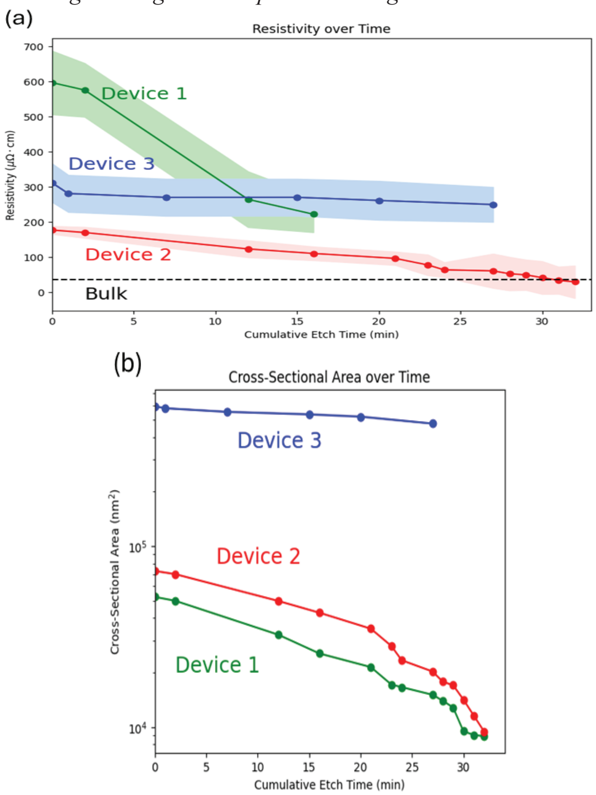

Figure 3: (a) Resistivity of NbAs devices as a function of total etch time. (b) Cross-sectional area of nanoslabs as a function of etch time.

There is a clear decreasing trend in resistivity as a function of cumulative etching time as shown in Figure 3. This supports the resistivity scaling trend of NbAs, and as the surface to volume ratio continuously increases from etching, the resistivity eventually falls below the bulk value while still decreasing.

SEM images in Figure 4 show considerable surface damage from RIE on the surface of the NbAs nanoslabs. However, the overall conductivity of the samples continues to exhibit decreasing behavior despite the surface damage.

Conclusions and Future Steps:

We progressively etched NbAs nanoslab devices through RIE at an etching rate of approximately 5-7 nm/min. We were further able to show that RIE is effective in reducing the size of NbAs without adversely affecting conductivity. We confirmed promising trend of decreasing resistivity for NbAs at decreasing dimensions in the nanoscale regime.

Future work would involve improving height measurements which are currently overestimated due to the geometry of the sample and FIB placement. Better methods to measure cross-sectional area would result in less overall error and a clearer understanding of our results. We would also like to continue investigating the surface contributions to the resistivity scaling of NbAs with RIE etching in future devices and investigate even less destructive methods of size reduction, whether it be through RIE or other means.

References:

[1] Joon-Seok Kim et al., Addressing interconnect challenges for enhanced computing performance. Science 386, eadk6189 (2024). DOI:10.1126/science.adk6189

[2] Asir Intisar Khan et al., Surface conduction and reduced electrical resistivity in ultrathin noncrystalline NbP semimetal. Science 387,62-67(2025). DOI:10.1126/science.adq7096

[3] Cheon, Y et al. https://arxiv.org/abs/2503.04621 (2025).

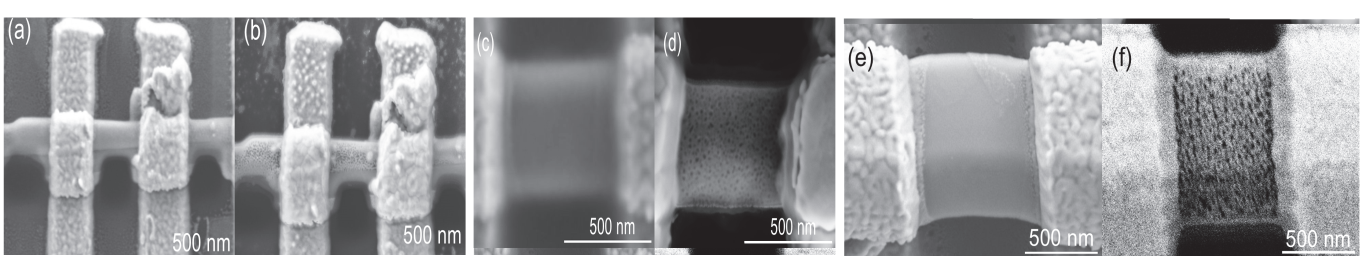

Figure 4: (a) Pre-etch SEM of Device 1. (b) Post-etch SEM of Device 1. (c) Pre-etch SEM of Device 2. (d) Post-etch SEM of Device 2. (e) Pre-etch SEM of Device 3. (f) Post-etch SEM of Device 3.